On Wireless Sensor Networks: Architectures, Protocols, Applications, and Management

Yazeed Al-Obaisat, Robin Braun
University of Technology, Sydney
Sydney, Australia
yazeedal@eng.uts.edu.au

Abstract

With the recent technological advances in wireless communications, integrated digital circuits, and micro electro mechanical systems (MEMS); development of wireless sensor networks has been enabled and become dramatically feasible. Wireless sensor networks (WSNs) are large networks made of a numerous number of sensor nodes with sensing, computation, and wireless communications capabilities. Many various routing, power management, and data dissemination protocols have been designed for wireless sensor networks (WSNs) dependent on both the network architecture and the applications that it is designed for. In this paper, we present the state of the art of wireless sensor networks' architecture and design features. Also, in this paper, we introduce recent work on routing protocols for WSNs and their design goals and challenges. Also, an overview of the application that WSNs assist in is presented. Finally, several open research questions of wireless sensor networks management and issues are suggested and put forward.

1 Introduction

With the recent technological advances in wireless communications, processor, low power, highly integrated digital electronics, and micro electro mechanical systems (MEMS) [1]; it becomes possible to significantly develop tiny and small size, low power, and low cost multifunctional sensor nodes. These nodes are capable of wireless communications, sensing and computation (software, hardware, algorithms). So, it is clear that wireless sensor network (WSN) is the result of the combination of sensor techniques, embedded techniques, distributed information processing, and communication mechanisms. A WSN is a network that is made of hundreds or thousands of these sensor nodes which are densely deployed in an unattended environment with the capabilities of sensing, wireless communications and computations (i.e., collecting and disseminating environmental data). Many different routing, power management and data dissemination protocols have been designed for WSNs, dependent on both the architecture of WSN and the applications that WSN is intended to support. These protocols support the practical existence of WSNs and efficiently make them an integral part of our lives in the real world. These protocols are different from conventional ones; in essence they need to support various unique requirements and constraints to make wireless sensor networks practically useful and operating, these requirements and constraints are introduced by factors such as: memory, small-size, low-power consumption, fault-tolerance, low-latency, scalability, adaptivity, and robustness.

Consequently; many different academic and industrial applications have been developed based on WSNs. These applications cover many aspects ranging from military to civilians applications. The idea beyond these applications is that; densely deploying sensor nodes with capabilities of sensing, wireless communications, and computation in an unattended environment will assist in measuring ambient conditions in that specific environment, and obtaining the characteristics about phenomenon surrounding these sensors. Moreover, other applications for wireless sensor networks can be seen in environmental monitoring and control field (e.g., robot control), high-security smart homes, tracking, and identifications and personalization [2]. Although there are some previous works on surveying WSNs [3], this survey is distinguished from these efforts in that; it integrates the design factors and requirements of routing, power management and data dissemination protocols for WSNs with the applications that these protocols are designed to support.

Our paper is structured as follows: the state of the art of wireless sensor networks architecture and the protocol stack are discussed in section 2. In sections 3 and 4, we present a review of the recent ongoing research on routing protocols for WSNs, describing their design goals, characteristics, challenges, classifications, assumptions, their advantages and drawbacks, and our recommendations and directions for improvements. Section 5, presents a brief review of the applications that based on WSNs with the focus on integrating these applications with the routing, power management and data dissemination protocols that support these applications. In section 6, several open research questions of WSNs management and issues are suggested and put forward. Finally, we outline our conclusions and highlight some recommendations and directions for future work in section 7.

2 The Communications Architecture of WSNs.

We mentioned above that a WSN is a network made of a numerous number of sensor nodes with sensing, wireless communications and computation capabilities. These sensor nodes are scattered in an unattended environment (i.e., sensor field) situated far from the user as shown in Fig.1.

The upper side of the architecture above in (Fig.1) represents the communication architecture for WSNs. The main entities that build up the architecture are [4]:

- The Sensor nodes that form the sensor network.
- The sink (Base Station) communicates with the user via internet or satellite communication.

• Phenomenon which is an entity of interest to the user to collect measurements about.

• The user who is interested in obtaining information about specific phenomenon to measure/monitor its behavior.

2.1 The Architecture of the Protocol Stack for Wireless Sensor Networks

The architecture of protocol stack [3] used by the sink and sensor nodes is shown in Fig. 2. This protocol stack integrates power and routing awareness (i.e., energy-aware routing), integrates data with networking protocols (i.e., data aggregation), communicates power efficiently through the wireless medium, and promotes cooperative efforts of sensor nodes (i.e., task management plane). This protocol stack (Fig. 2) is made up of physical layer, data link layer, network layer, transport layer, application layer, power management plane, mobility management plane, and task management plane. The physical layer addresses the needs of a robust modulation, transmission and receiving techniques. The network layer takes care of routing the data supplied by the transport layer. The transport layer helps to maintain the flow of data if the wireless sensor network application requires it. Depending on the sensing tasks, different types of application Software can be set up and used on the application layer.

The power management plane manages how a sensor node uses its power and manages its power consumption among the three operations (sensing, computation, and wireless communications). For instance, to avoid getting duplicated messages, a sensor node may turn off it receiver after receiving a message from one of its neighbors. Also, a sensor node broadcasts to its neighbors that it is low in power and can not take part in routing messages. The remaining power is reserved for sensing and detecting tasks. The mobility management plane detects and registers the movement/mobility of sensor nodes as a network control primitive. Hence; a route back to the user is always kept, and sensor nodes can keep track of who their neighbors of other sensor nodes are. Therefore, the nodes can balance their power and task usage by knowing this situation. The task management plane (i.e., cooperative efforts of sensor nodes) balances and schedules the events' sensing and detecting tasks from a specific area. Hence; not all of the sensor nodes in that specific area are required to carry out the sensing tasks at the same time. Depending on their power level, some nodes perform the sensing task more than others.

3 Sensor Networks Protocols

3.1 Design Challenges

Many design factors have been addressed by many researchers in this field; such as Reliability, Scalability, Topology, Energy Consumption, Hardware constraints, Data fusion, Security, Self-Configuration, Network dynamics and Quality of Service, and Connectivity and Coverage. Some recommended solutions to these challenges are as follows: a reduction in the active duty cycle for each sensor node, a minimization of data communications over the wireless channel (i.e., aggregation, communicate network state summaries instead of actual data), and maximization of network life time (i.e., minimum energy routing) will give hand to the energy depletion challenge. Scalability, on another hand; may be enhanced by organizing network in a hierarchical manner (e.g., clustering) and utilizing localized algorithms with localized interactions among sensor nodes, while robustness to environmental changes, may be improved through self-organizing, self-healing, self-configuring, and self-adaptive networks.

3.2 Classification of Sensor Networks Routing Protocols

There are different ways by which we can classify the sensor networks' routing protocols. According to network structure, these routing protocols can be classified as flat, hierarchical, and location-based protocols. Also, these protocols can be classified into multipath-based, query-based, negotiation-based Quality of Service (QoS)-based, or coherent-based depending on the protocol operation. Moreover, these protocols can be classified into three categories, namely, reactive, proactive, and hybrid protocols depending on route discovery. In flat-based routing, all nodes are assigned the same roles or functionalities. In hierarchical-based routing, nodes will play different roles or functionalities, aiming at routing techniques clustering the nodes with different roles so that the heads of the cluster can do some data aggregation or confusion in order to save power, while in location-based routing; sensor nodes' positions are exploited to route the data to specific regions other than the whole network. On the other hand; in reactive protocols, routes are computed on demand. In proactive protocols, routes are computed before they are needed, while hybrid protocols utilize a combination of the ideas of both reactive and proactive protocols.

4 Routing Protocols for WSNs

In this context, we introduce the most well-known routing protocols for wireless sensor networks. In this context, we introduce the most well-known routing protocols for wireless sensor networks.

A. Flooding

Flooding [5] is an old routing mechanism that may also be used in sensor networks. In flooding, a node sends out the received data or the management packets to its neighbors by broadcasting, unless a maximum number of hops for that packet are reached or the destination of the packets is arrived. However; there are some deficiencies for this routing technique [5]:

• Implosion: is the case where a duplicated data or packets are sent to the same node. Flooding is a function of the network topology.

• Overlap: if two sensor nodes cover an overlapping measuring region, both of them will sense/detect the same data. As a result, their neighbor nodes will receive duplicated data or messages. Overlapping is a function of both the network topology and the mapping of sensed data to sensor nodes.

• Resource blindness: In flooding, nodes do not take into account the amount of energy resource available to them at a given time. A WSN protocol must be energy resource-aware and adapts its sensing, communication and computation to the state of its energy.

B. GOSSIPING

Gossiping protocol is an alternative to flooding mechanism. In Gossiping [6], nodes can forward the incoming data/packets to randomly selected neighbor node. Once a gossiping node receives the messages, it can forward the data back to that neighbor or to another one randomly selected neighbor node. This technique assists in energy conservation by randomization. Although, gossiping can solve the implosion problem, it can not avoid the overlapping problem. On the other hand; gossiping distribute information slowly, this means it consumes energy at a slow rate, but the cost is long-time propagation is needed to send messages to all sensor nodes.

C. SPIN

SPIN (Sensor Protocols for Information via Negotiation) [7] is a family of adaptive protocols for WSNs. Their design goal is to avoid the drawbacks of flooding protocols mentioned above by utilizing data negotiation and resource-adaptive algorithms. SPIN is designed based on two basic ideas; (1) to operate efficiently and to conserve energy by sending meta-data (i.e., sending data about sensor data instead of sending the whole data that sensor nodes already have or need to obtain), and (2) nodes in a network must be aware of changes in their own energy resources and adapt to these changes to extend the operating lifetime of the system. SPIN has three types of messages, namely, ADV, REQ, and DATA.

• ADV: when a node has data to send, it advertises via broadcasting this message containing meta-data (i.e., descriptor) to all nodes in the network.

• REQ: an interested node sends this message when it wishes to receive some data.

• DATA: Data message contains the actual sensor data along with meta-data header. SPIN is based on data-centric routing where the sensor nodes send ADV message via broadcasting for the data they have and wait for REQ messages from interested sinks or nodes. The semantics of SPIN's meta-data format is application dependent and not supported by SPIN. In another words; SPIN uses application specific meta-data to name the sensed data. Although, SPIN has some advantages, such as (1) solving the problems associated with classic flooding protocols, and (2) topological changes are localized, it has its own drawbacks like; (1) scalability, SPIN is not scalable, (2) if the sink is interested in too many events, this could make the sensor nodes around it deplete their energy, and (3) SPIN's data advertisement technique can not guarantee the delivery of data if the interested nodes are far away from the source node and the nodes in between are not interested in that data.

D. Directed Diffusion

Directed diffusion [8] is another data dissemination and aggregation protocol. It is a data-centric and application aware routing protocol for WSNs. It aims at naming all data generated by sensor nodes by attribute-value pairs. Directed diffusion consists of several elements; first of all, naming; where task descriptors, sent out by the sink, are named by assigning attribute-value pairs. Secondly, interests and gradients; the named task description constitutes an interest that contains timestamp field and several gradient fields. Each node stores the interest in its interest cache. As the interests propagate throughout the network, the gradients from the source back to the sink are set up. Thirdly, data propagation, when the source has data for the interest, it sends out the data to the interest (i.e., sink) along the interest's gradient path. Fourthly, after the interest (sink) starts receiving low rate data events, it reinforce one particular neighbor to draw down higher quality (higher data rate) events. This feature of directed diffusion is achieved by data-driven local rules. Directed diffusion assists in saving sensors' energy by selecting good paths by caching and processing data in-network since each node has the ability for performing data aggregation and caching. On the other hand; Directed diffusion has its limitations such as; implementing data aggregation requires deployment of synchronization techniques which is not realizable in WSNs. Also, the overhead in data aggregation involves recording information. These two drawbacks may contribute to the cost of sensor node, which is not desired.

E. LEACH

LEACH (Low Energy Adaptive Clustering Hierarchy) [9] is a self-organizing, adaptive clustering-based protocol that uses randomized rotation of cluster-heads to evenly distribute the energy load among the sensor nodes in the network. LEACH based on two basic assumptions: (a) base station is fixed and located far away from the sensors, and (b) all nodes in the network are homogeneous and energy-constrained. The idea behind LEACH is to form clusters of the sensor nodes depending on the received signal strength and use local cluster heads as routers to route data to the base station. The key features of LEACH are:

• Localized coordination and control for cluster set-up and operation.

• Randomized rotation of the cluster "base stations" or "cluster heads" and the corresponding clusters.

• Local compression to reduce global communication.

In LEACH, the operation is separated into fixed-length rounds, where each round starts with a setup phase followed by a steady-state phase. The duration of a round is determined priori.

1. Advertisement phase
2. Cluster set-up phase
3. Schedule Creation phase
4. Data Transmission phase.

Although, LEACH has shown good features to sensor networks, it suffers from the following drawbacks:

• It can not be applied to time-constrained application as it results in a long latency.

• The nodes on the route a hot spot to the sink could drain their power fast. This problem known as "hot spot" problem.

• The number of clusters may not be fixed every round [10].

• It can not be applied to large sensor networks.

F. PEGASIS

PEGASIS (Power-Efficient GAthering in Sensor Information Systems) is a greedy chain-based power efficient algorithm [11]. Also, PEGASIS is based on LEACH (the scenario and the radio model in PEGASIS are the same as in LEACH). The key features of PEGASIS are

• The BS is fixed at a far distance from the sensor nodes.

• The sensor nodes are homogeneous and energy constrained with uniform energy.

• No mobility of sensor nodes.

PEGASIS is based on two ideas; Chaining, and Data Fusion. In PEGASIS, each node can take turn of being a leader of the chain, where the chain can be constructed using greedy algorithms that are deployed by the sensor nodes. PEGASIS assumes that sensor nodes have a global knowledge of the network, nodes are stationary (no movement of sensor nodes), and nodes have location information about all other nodes. PEGASIS performs data fusion except the end nodes in the chain. PEGASIS outperforms LEACH by eliminating the overhead of dynamic cluster formation, minimizing the sum of distances that non leader-nodes must transmit, limiting the number of transmissions and receives among all nodes, and using only one transmission to the BS per round. PEGASIS has the same problems that LEACH suffers from. Also, PEGASIS does not scale, can not be applied to sensor network where global knowledge of the network is not easy to get.

H. GEAR

GEAR (Geographical and Energy Aware Routing) [12] is a recursive data dissemination protocol WSNs. It uses energy aware and geographically informed neighbor selection heuristics to rout a packet to the targeted region. Within that region, it uses a recursive a geographic informed mechanism to disseminate the packet. GEAR, like other sensor networks protocols, developed according to some assumptions in mind:

• Sensor nodes are static (i.e., immobile).

• There is an existence of a localization system that enables each node to know its current position.

• Sensor nodes are energy-constrained accompanied with location information about all other nodes (i.e., each node knows its location and its energy level, and its neighbor's location and remaining energy level.

• The link that connects nodes is bi-directional. GEAR has two phases: (1) forwarding the packets toward the targeted region, and (2) forwarding the packets within the targeted region R. Although GEAR reduces the energy consumption for the route set up. it is not scalable and does not support data diffusion.

Based on the analysis and thorough survey of the mentioned protocols, we believe that an efficient routing protocol for wireless sensor networks should have some key features, such as:

• Data Aggregation: we believe that reducing the data size quickly using computation will play a key role in supporting efficient query processing, and reducing the overall network overhead. Hence saving power.

• Dynamic clustering architecture is required. Since such architecture will preclude cluster heads from depleting their energy quickly. Hence, long network's lifetime.

• Threshold for sensor nodes on data transmission and dissemination: this will help in saving energy by reducing unnecessary transmissions (i.e., redundancy) and giving the network long lifetime.

• Randomized path selection: multi-path selection to destination could improve fault tolerance and handle the overhead of network load.

• Mobility: most of the current protocols assume that sensor nodes are static (i.e., immobile). However, for some applications, nodes need to be mobile. Hence, new routing algorithms are needed to handle the mobility and network topology changes.

• Self-configuration: since sensor nodes are prone to failure due to some factors or new sensor nodes may join the network, an update, self-configuration, self-healing, and adaptation to changes in network topology or environmental changes should be considered.

• Security: there is a desperate need to develop distributed security approaches for wireless sensor network. Hence, achieving secure routing.

• Quality-of-Service, dependability, and localization need to be considered and given more attention.

• Time synchronization.

5 Applications

Sensor networks are applied in a wide range of areas, such as military applications, public safety, medical, surveillances, environmental monitoring, commercial applications, habitat and tracking [13]. In general, sensor networks will be ubiquitous in the near future, since they support new opportunities for the interaction between humans and their physical world. In addition, sensor networks are expected to contribute significantly to pervasive computing and space exploration in the next decade. Deploying sensor nodes in an unattended environment will give much more possibilities for the exploration of new applications in the real world (see Fig.3).

6 Wireless Sensor Networks Management

Sensor networks have different architecture than traditional wired data networks. Sensor networks are set up in a random manner. On the other hand, the WSNs are applications-dependent which implies that the management requirements also change among sensor networks, and a configuration error of a WSN in unpredictable situations may cause the fail and/or loss of the whole entire network even before it starts to operate. Also, the behavior of WSN is highly unpredictable and dynamic. All these factors have to be incorporated by various sensor network models that describe the current network's states. Some of the possible suggested models are:

• Network Topology Model: it describes the actual topology map and the connectivity and/or reachability of the network. It also may assist routing operations and obtaining information a bout future deployment of nodes [14], since the topology of a network affects many of its characteristics, such as latency, capacity, and robustness, as well as the complexity of data routing and processing. This requires careful handling of network topology maintenance [3]. Paper [3] defined three phases related to topology maintenance and changes (e.g., malfunctioning of some sensor nodes); Pre-deployment and deployment phase, Post-deployment phase, and Re-deployment of additional nodes phase.

• Residual Energy Model: describes the remaining energy level of the nodes or the network. Using this information as well as the data from network topology, coupled together; would make it possible to identify the weak areas (i.e., areas that have short lifetime) of the network [14].

Cost Model: describes the cost of equipment, energy, and human cost to maintain the desired performance levels of the network.

Usage Patterns Model: represents the activity of the network in terms of period of time for nodes' activity, quantity of data transmitted per sensor unit or the movements made by the target, and tracking of hot spots in the network to avoid hot spot problem [14].

Behavioral Model: describes the behavior of the network. Since sensor networks are highly unpredictable, dynamic, and unreliable, statistical and probabilistic models may be much more efficient in estimating the network behavior than estimating the network behavior than deterministic models.

• Coverage Area Model: a sensing coverage area map that represents the actual sensor's view of the environment and communications coverage map that describes the communication coverage area from the range of the RF transceiver [14].

The above models would build up the MIB (management Information base). Also, these models could be used for different network management functions such as: deployment of sensors, network operating parameters, coverage area supervision function, topology map discovery function, network connectivity discovery function, node localization discovery function, prediction function for future network states, monitored area definition function, design of sensor networks, energy level function, self-test function [14,15,16]. Since sensor nodes are unattended as well as the environment these sensors are situated in; human intervention to perform some network maintenance tasks, such as configuration, protection, healing, and energy replenishment is becoming impractical. So, it is our belief that self-management solutions (self-configuration, self-healing, self-optimization, self-protection, self-service, self awareness, and self knowledge) [15,16], are promising functional key management solutions that can cope with the various unique requirements and constraints imposed on WSNs due to resource restrictions introduced by some factors (e.g., small-size, memory, low-power consumption, fault-tolerance, low-latency, scalability, adaptivity, and robustness). Attempts to build up management system that can combine all of these features are proposed by some interested researchers in this field. L. B. Ruiz, et al. [17,18], have proposed an architecture for WSN management called "MANNA". Also, other attempts have been carried out on the power management for WSNs [19,20]. Also, it is our belief that sensor network management could borrow from artificial intelligence approach, in general, swarm intelligence [21], in particular, to achieve scalable, robust, and adaptable management system for WSNs. Different algorithms, optimization techniques, and collective intelligence could be adapted and brought to the field of wireless sensor network.

7 Conclusion

In this paper, we presented the state of the art of wireless sensor networks; their architecture, routing protocols for WSNs, their applications. Also, in this paper, we introduced some recommendation and directions as guidelines and hints that would assist and give enhancements to the future design of protocols and algorithms for wireless sensor networks. Also, in this paper, a brief review of the application based on wireless sensor networks is given. Finally, our directions and recommendations for wireless sensor network management are suggested and put forward.

8 References

[1] B. Warneke, K.S.J. Pister, "MEMS for Distributed Wireless Sensor Networks," in Proc. of 9th International Conf. on Electronics, Circuits and Systems, Dubrovnik, Croatia, September, 2002.

[2] R. Min, et al., "Low Power Wireless Sensor Networks", in the Proceedings of International Conference on VLSI Design, Bangalore, India, January 2001.

[3] I. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "A survey on Sensor Networks," IEEE Communications Magazine, vol. 40, Issue: 8, pp. 102-114, August 2002.

[4] S. Tilak, N. Abu-Ghazaleh, and W. Heinzelman, "A taxonomy of Wireless Micro-senor Network Models," ACM SIGMOBILE, Mobile Computing and Communications Review, vol.6, issue: 2, pp. 28-36, April, 2002.

[5] W. R. Heinzelman, J. Kulik, and H. Balakrishnan, "Adaptive Protocols for Information Dissemination in Wireless Sensor Networks," in proc. ACM MobiCom '99, Seattle, WA, 1999.

[6] S. M. Hedetniemi, S. H. Hedetniemi, and A. Liestman, "A Survey of Gossiping and Broadcasting in Communication Networks," Networks, vol. 18, 1988.

[7] J. Kulik, W. R. Heinzelman, and H. Balakrishnan, "Negotiation base protocols for Disseminating Information in Wireless Sensor Networks," Wireless Networks, vol. 8, pp. 169-185, 2002.

[8] C. Intanagonwiwat, R. Govindan, D. Estrin, J. Heidemann, and F. Silva, "Directed Diffusion for Wireless Sensor Networking," IEEE/ACM Transactions on Networking, vol. 11, pp. 2-16, Feb. 2003.

[9] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Micro-Sensor Networks," in Proc. of the 33rd Annual Hawaii International Conf. on System Sciences, pp. 3005-3014, 2000.

[10] S. Dai; X. Jing; L. Li, "Research and analysis on routing protocols for wireless sensor networks," In Proc. of International Conference on Communications, Circuits and Systems, vol. 1, pp. 407 - 411, 27-30 May, 2005.

[11] S. Lindsey, C. S. Raghavendra, "PEGASIS: Power-Efficient Gathering in Sensor Information Systems," presented at Proc. of IEEE Aerospace Conference, Montana, 2002.

[12] Y. Yu, R. Govindan, D. Estrin, "Geographical and Energy Aware Routing: A Recursive Data Dissemination Protocol for Wireless Sensor Networks," UCLA Computer Science Department UCLA-CSD TR-01-0023, May, 2001.

[13] Ning Xu, "A Survey of Sensor Network Applications," available form the World Wide Web: http://enl.usc.edu/ningxu/papers/survey.pdf

[14] S. B. B. Deb and B. Nath, "A Topology Discovery Algorithm for Sensor Networks with Applications to Network Management," Tech. rep. DCSTR-441, Dept. of Computer Science, Rutgers Univ., May 2002.

[15] L.B. Ruiz, T.R.M. Braga,; F.A. Silva,; H.P. Assuncao, J.M.S. Nogueira, A.A.F. Loureiro, "On the Design of a Self-Managed Wireless Sensor Network," Communications Magazine, IEEE, vol. 43, Issue 8, pp.95 - 102, Aug. 2005.

[16] IBM, "An Architectural Blueprint For Autonomic Computing," IBM and Autonomic Computing, April 2003. Available from the world wide web : http://www-03.ibm.com/autonomic/pdfs/ACwpFinal.pdf

[17] L. B. Ruiz, J. M. S. Nogueira, and A. A. F. Loureiro, "MANNA: A Management Architecture for Wireless Sensor Networks," IEEE Communication Magazine, vol. 41, no. 2, pp. 116-25, Feb. 2003.

[18] L.B. Ruiz, F.A. Silva, T.R.M. Braga, J.M.S. Nogueira, A.A.F. Loureiro, "On Impact of Management in Wireless Sensors Networks" In Proc. of the 9th IEEE/IFIP Network Operations and Management Symposium (NOMS' 04)vol. 1, pp. 657 - 670, Seoul, Korea, 19-23 April, 2004.

[19] R.M. Passos, C.J.N. Coelho, A.A.F. Loureiro, R.A.F. Mini, "Dynamic Power Management in Wireless Sensor Networks: An Application-Driven Approach," In Proc. of the 2nd Annu. Conference on Wireless On-demand Network Systems and Services (WONS '05), pp. 109 - 118, 19-21 Jan. 2005.

[20] R. Tynan, D.Marsh, D. O'Kane, G.M.P. O'Hare, "Agents for wireless sensor network power management," In Proc of International Conference workshops on Parallel Processing (ICPP '05) Workshops, pp. 413 - 418, 14-17 June 2005.

[21] E. Bonabeau, M. Dorigo, and G. Theraulaz, Swarm Intelligence: From Natural to Artificial Systems, Santa Fe Institute Studies in the Sciences of Complexity, Oxford University Press, 1999.

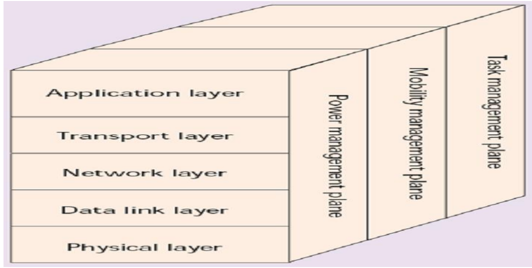

Figure 1: The wireless sensor networks protocol stack (source [3]).

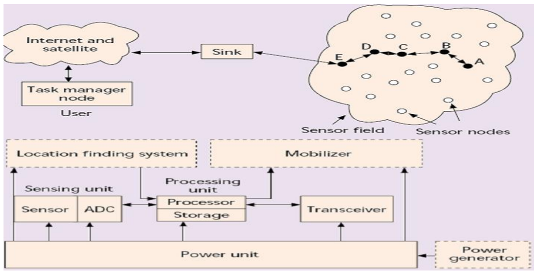

Figure 2: Sensor nodes scattered in a sensor field And The Components of a single sensor node (source [3]).

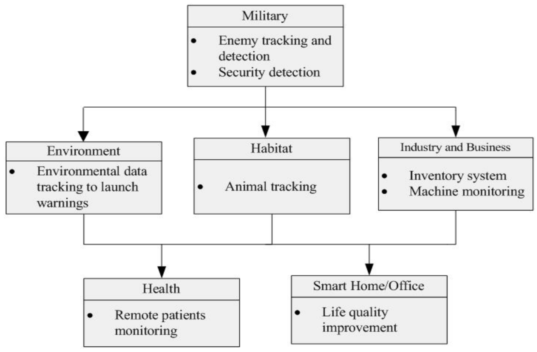

Figure 3: Sensor Network Applications Development.

Table 1: Comparison of some of the routing protocols in Wireless Sensor Network. Loc:Localization, Lo-A: Location Awareness.

	Class-tion	Scalability	Mobility	Data-Agg	Energy Usage	Loc	QoS	Multihop	Query	Lo-A
Flooding	Flat	Limited	No	No	High	No	No	Yes	No	No
SPIN	Data-centric	Limited	Possible	No	Limited	No	No	Yes	Yes	No
Directed	Flat	Limited	Limited	Yes	Limited	Yes	No	Yes	Yes	No
LEACH	Hierarchical	Good	Fixed BS	Yes	High	Yes	No	No	No	No
PEGASIS	Hierarchical	Good	Fixed BS	No	High	Yes	No	No	No	No
GEAR	Location	Limited	Limited	No	Limited	No	No	Yes	No	Yes